Threshold Effects in Charm Hadroproduction*

Nikolaos Kidonakis,† Eric Laenen,‡ Sven Moch,§ and Ramona Vogt

Calculations of charm production are still not under solid theoretical control. A good understanding of the charm cross section is of particular interest for heavy ion physics. Charm is an important contribution to the dilepton continuum so that its total rate would be a useful J/ψ reference.

Although many future heavy ion experiments will be at collider energies, some experiments are in the near-threshold region. NA60 will take heavy ion data at $\sqrt{S} = 17.3$ GeV and pA data at $\sqrt{S} = 29.1$ GeV. A new facility at the GSI will measure charm near threshold with $\sqrt{S} = 6.98$ GeV.

Because the charm quark mass is a few times $\Lambda_{\rm QCD}$, it is generally treated as a heavy quark. However, its relative lightness results in a rather strong dependence on mass and scale, with up to a factor of 100 between the lowest and highest next-to-leading order (NLO) cross sections.

Improvements in the charm calculation are perhaps possible when the $c\overline{c}$ pair is produced close to threshold. Factorization separates cross sections into universal, nonperturbative parton densities and the perturbative partonic cross section. Singular functions, remnants of long-distance dynamics in the partonic cross section, can dominate higher order corrections near production threshold. Threshold resummation techniques organize these singular distributions to all orders in the form of plus distributions, of the form $[\ln^l x/x]_+$, where x denotes the 'distance' from partonic threshold. At next-to-leading log (NLL) accuracy and beyond, proper account must be taken of the color structure of the hard scattering for each partonic subprocess.

Resummed cross sections are useful as generating functions for approximate finite order corrections when expanded in powers of α_s. The resummed charm cross section to leading log (LL) was previously calculated [1]. Because the ratio m/Λ_3 is quite small, the expansion parameter, α_s, is not and the LL resummation began to fail at $\sqrt{S} \approx 20$ GeV.

We work at finite order to calculate the heavy quark hadroproduction cross sections to next-to-next-to-leading order (NNLO), $O(\alpha_s^4)$, and next-to-next-to-leading logarithm (NNLL), as in Ref. [2]. The distance from partonic threshold in the singular functions depends on the kinematics. We either integrate over the momentum of the unobserved Q or $\overline{Q}$ and determine the one-particle inclusive (1PI) cross section for the detected quark or treat the Q and $\overline{Q}$ as a pair, pair invariant mass (PIM) kinematics.

We add the $O(\alpha_s^4)$ NNLL approximate contribution to the exact NLO $q\overline{q}$ and gg cross sections. We apply a damping factor, $2m/\sqrt{s}$ where $\sqrt{s}$ is the partonic center of mass energy, to temper the influence of contributions further from threshold. We find the greatest difference in the kinematics schemes for $\mu = m$. The effect of the NNLO-NNLL terms is reduced for higher scales because $\alpha_s(m) > \alpha_s(2m)$. The running of α_s is significant because the mass is rather low, ensuring a large scale dependence for charm production. Results for $pp \to c\overline{c}$ are shown in the figure for $m = 1.2$, 1.5 and 1.8 GeV and $\mu = m$ and $2m$. We use the GRV 98 HO parton densities [3].

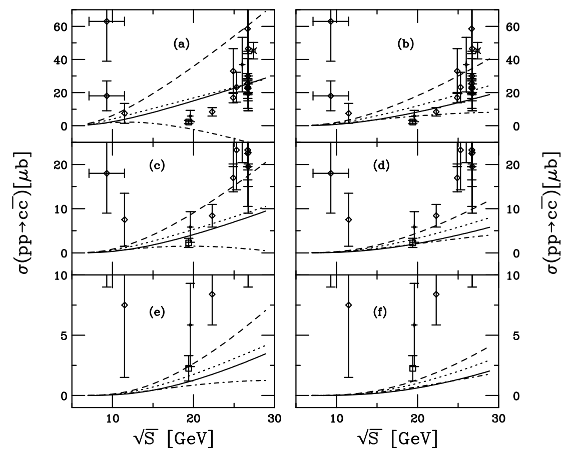

FIG. 1: The total $pp \to c\overline{c}$ cross sections as a function of $\sqrt{S}$. The left-hand side employs the scale $\mu = m$, the right-hand side, $\mu = 2m$. From top to bottom, $m = 1.2$ GeV in (a) and (b), 1.5 GeV in (c) and (d), and 1.8 GeV in (e) and (f). We show the exact NLO result (solid curves), 1PI NNLO-NNLL (dashed), PIM NNLO-NNLL (dot-dashed), and the 1PI and PIM average (dotted).

We studied the behavior of NNLO-NNLL calculations for charm production near threshold in pp and $\pi^- p$ interactions in both 1PI and PIM kinematics. There are large differences in the 1PI and PIM results. Thus, the uncertainties in the cross sections remain large even at NNLO-NNLL. The average of the 1PI and PIM results exhibits better convergence and less scale dependence. The average also lies above the NLO cross section for both pp and $\pi^- p$ interactions. Thus, the charm mass need not be too low to agree with the data. However the poor convergence properties as well as other uncertainties of the 1PI and PIM results make any quantitative statement about the inclusive charm hadroproduction cross section difficult.

* LBNL-51590, Cavendish-HEP-02/16, NIKHEF/2002-014, ITP-2002/62, DESY 02-216, Phys. Rev. **D67** (2003) 074037.
† Cavendish Laboratory, University of Cambridge, UK
‡ NIKHEF Theory Group, NIKHEF, The Netherlands and Institute for Theoretical Physics, Utrecht University, The Netherlands
§ DESY-Zeuthen, Zeuthen, Germany

[1] J. Smith and R. Vogt, Z. Phys. C**75**, 271 (1997).
[2] N. Kidonakis, E. Laenen, S. Moch and R. Vogt, Phys. Rev. **D64** (2001) 114001.
[3] M. Glück, E. Reya and A. Vogt, Eur. Phys. J. C**5**, 461 (1998).